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THE DESIGN OF AIRFIELD OVERLAY PAVEMENTS

Progress Report of the Committee on Design of Overlay Pavements of the Air Transport Division

(Discussion open until December 1, 1955)

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THE DESIGN OF AIRFIELD OVERLAY PAVEMENTS

Progress Report of the Air Transport Division

INTRODUCTION

Many of the airfields in use today, both civilian and military, were designed primarily for the military at the beginning of World War II and during the course of the war. Since then there has been a considerable increase not only in the gross weight of aircraft but also in the tire contact pressure. For example, during World War II the so-called heavy bombers were the B-17 (Flying Fortress) and the B-24, each having a maximum gross weight of around 60,000 lb. and tire pressures of approximately 80 psi. Today the gross weights of our military aircraft are well in excess of 100,000 lb., ranging from 150,000 lb. for the B-50 to close to 400,000 lb. for the B-36 and the B-52 intercontinental bombers. Likewise the tire pressures have increased to well over 100 psi.

In commercial aviation the trend has also been toward larger aircraft. During World War II the DC-3 (gross weight approximately 25,000 lb.) used by many of the airlines has been replaced by Convairs, DC-6's, DC-7's, Constellations and Stratocruisers, ranging from 45,000 lb. to nearly 150,000 lb.

Because few airfields were originally designed for these heavy loads and high tire pressures, and because the cost of abandoning existing facilities was prohibitive, the airport designer was confronted with the problem of strengthening existing pavements to meet the requirements of modern aircraft.

The objective of the Committee was to summarize the methods currently available for designing overlay pavements, the investigational work now being conducted or planned in the near future and other material pertinent to the problem.

TYPES OF OVERLAY PAVEMENTS

All fields of engineering require the use of terms to describe the physical components of a structure. Overlay pavement design is a relatively new field, hence no widely accepted nomenclature has been developed. The nomenclature presented in this report represents current usage by organizations engaged in this field, with minor modifications by the committee.

There are many types of overlay pavements. For example, an existing concrete pavement can be overlaid with additional concrete, a bituminous surfacing, or a combination of aggregate base course and a bituminous surfacing. Likewise, an existing flexible type pavement can be overlaid with concrete, a bituminous surfacing, or the combination cited above. The various types of pavements are defined as follows:

Existing Pavement - The existing pavement on which the overlay is to be placed. The existing pavement may be of Portland cement concrete (referred to as rigid pavement) or a bituminous wearing course on an aggregate base course and a subbase (referred to as a flexible pavement).

Overlay Pavement - The thickness of rigid or flexible type pavement placed on the Existing Pavement.

Portland Cement Concrete Overlay - An overlay pavement constructed of Portland cement concrete.

Bituminous Overlay - An overlay consisting entirely of a bituminous surfacing.

Flexible Overlay - An overlay consisting of a base course and a bituminous surfacing.

CURRENT DESIGN PROCEDURES

The overlay design procedures described in this report were developed by the Corps of Engineers, U. S. Army, the Bureau of Yards and Docks, U. S. Navy, and the Civil Aeronautics Administration. The Corps of Engineers and the CAA methods are based on results of full scale test sections together with observations of behavior of overlays in service and are projected on theoretical considerations. The Navy procedure is based partly on theoretical considerations and in part on proof testing at the site by plate loading tests.

Corps of Engineers Method of Design

Overlays on Flexible Pavements

Bituminous or flexible Overlays

The required thickness of bituminous or flexible overlay is determined by utilizing the CBR design procedure for determining the thickness of new pavements.(1) On the basis of soil tests, drainage and climate, the CBR of the subgrade underlying the existing pavement is determined. From the basic design curves,(1,2) of which Fig. 1 is an example for 100 psi tire pressure (there are other curves for the same loads at higher tire pressures which are not shown here), the thickness of flexible pavement required for the particular wheel loading under consideration, assuming it is to be placed directly on the subgrade, is determined. The difference between the total thickness as determined from the design curves and the thickness of the existing pavement represents the required thickness of overlay pavement. The Corps of Engineers recommends that the base course thickness in a flexible overlay be not less than 4 in. If the resulting overlay results in a base course thickness less than 4 in. it is required that the entire overlay be of the bituminous type.

Portland Cement Concrete Overlays

There is no specific method of design for a Portland cement concrete overlay on a flexible pavement. The problem is treated as new construction on a subgrade consisting of the existing flexible pavement. The Westergaard analysis(3,4,5) is used to determine the thickness of the Portland cement concrete overlay. It is necessary to make plate bearing tests on the existing flexible pavement and establish the value of the subgrade modulus, "k." No reduction in thickness of Portland cement concrete may be made even though the existing flexible pavement may be close to the full thickness required. The reason for this is that the strength of a Portland cement concrete slab is very critical with respect to the thickness. The normal deflection to be expected of a flexible pavement is about 0.25 in., whereas the deflection of a

rigid pavement sufficient to cause the pavement to break is about 0.10 in. Unless this deflection is limited, the rigid pavement will crack and lose its effectiveness.

Overlays on Existing Rigid Pavements

The Corps of Engineers design procedure for overlays on Portland cement concrete is largely based on observation at military airfields and specially prepared test sections. At Maxwell Field, Alabama, and MacDill Field near Tampa, Florida, bituminous and flexible overlays of various thicknesses were applied to the Portland cement concrete pavements and accelerated traffic tests conducted on the overlays. The test sections completed to date are as follows:

Project	Overlay Types	Gear Configuration
Lockbourne No. 1	Concrete Overlays	Single Wheel Gear - Low pressure tires
Lockbourne No. 2	Concrete Overlays	Single Wheel Gear - Low pressure tires
MacDill Field, Florida	Concrete, Flexible and all A.C. Overlays	Twin Wheel Gear - Low pressure tires
Maxwell Field, Alabama	Flexible and all A.C. Overlays	Twin Wheel Gear - Low pressure tires
Lockbourne No. 3	Flexible and all A.C. Overlays	Twin Wheel Gear - Low pressure tires
Sharonville No. 1	Flexible and all A.C. Overlays	Twin Wheel Gear - high pressure tires
Sharonville No. 3	All A.C. Overlays of badly broken concrete	Single Wheel Gear - high pressure tires

A test track, Sharonville No. 2, is currently being tested with a Twin Wheel Gear, high pressure tires, for the purpose of further checking the flexible, all bituminous, and rigid overlay design methods and investigating thick all bituminous overlays of rigid pavements.

Bituminous and Flexible Overlays

The curves and accompanying design procedure given by Fig. 3 apply to both Bituminous and Flexible Overlays. The Corps of Engineers recommends that the minimum thickness of overlay be 4 in.; also that for overlays less than 8-in. thick, a bituminous overlay be used. This latter requirement is for the purpose of not permitting stabilized aggregate base course from being less than 4-in. thick. Experience with equivalent thicknesses of bituminous and flexible type overlays over similar thicknesses of concrete base slabs under repetitive traffic loading indicate no structural advantage of the flexible type overlay over the bituminous type overlay. This experience is limited, however, to high quality macadam or crushed rock bases for the flexible overlays. Therefore, such bases, or their equivalent, should be specified for the flexible overlay designs derived from Fig. 3. To further illustrate the application of Fig. 3 to the design of non-rigid overlays, let it be assumed that an

existing 6-in. concrete pavement is to be reinforced to carry a 30,000-pound single wheel load with a tire pressure of 100 psi. The subgrade modulus "k" is 200 lbs/in^3 and the flexural strength of the concrete base pavement is 700 psi.

Then:

h = 6 in.

h_E = 9.0 in. from Fig. 2

F = .94 for taxiways and .83 for runway interiors.

This is obtained from the curves of Fig. 3. Therefore, the overlay thickness "t" will be computed as follows:

$t = 2.5\ (.94 \times 9.0 - 6.0)$

or t = 6 in., Taxiways, aprons, etc.

$t = 2.5\ (.83 \times 9.0 - 6.0)$

or t = 4 in., Runway Interior

The runway interior is the portion of the runway between the 1000-foot ends.

In some cases when applying Fig. 3, where the subgrade modulus is 300 $lbs/in.^3$ or greater, the total thickness of overlay and base pavement may be greater than the equivalent thickness required for a flexible pavement. In this case the flexible pavement design is used considering the concrete as high quality base course. However, in no instance is a thickness of less than 4 in. used for the overlay.

The relationship between the subgrade modulus and the "F" factor given by the curves of Fig. 3 have been developed from the results of traffic tests on plain concrete pavements. The full program and some results of these tests are described in references 15 and 16. The factor "2.5" given in the equation for overlay thickness on Fig. 3 was developed from the results of the full scale traffic tests of the overlay test projects listed in the preceding paragraph.

It is further pointed out that this method of non-rigid overlay design assumes that the base pavement will break up into pieces having an area of approximately 5 to 7 square feet by the end of the pavement life. This period of useful pavement life may vary from 10 to 20 years, depending on the number and frequency of application of the design loading.

Portland Cement Concrete Overlay

The thickness of Portland cement concrete overlay slab may be determined by means of the following formulas:

$$h_c = h^{1.87} - Ch_e^2 \ldots\ldots (1)$$

or

$$h_c = h^2 - Ch_e^2 \ldots\ldots\ldots (2)$$

h_c = thickness of overlay slab in inches.

h_e = thickness of existing slab in inches.

h = thickness of equivalent single slab placed directly on the subgrade with a working stress equal to that of the overlay slab.

C = coefficient, depending on condition of existing pavement.

C = 1, existing pavement in good condition.

= 0.75, existing pavement with initial corner cracks due to loading, but no progressive cracks.

= 0.35 existing pavement badly cracked or crushed.

Intermediate values of "C" are not used presently in design. The change in overlay thickness requirement normally is approximately one inch for a change of "C" from 1.0 to 0.75 or 0.75 to 0.35.

Formula (1) is used where the overlay pavement is placed directly on the existing pavement and formula (2) is used where a separation course between the two pavements is required. It is recommended that no overlay slab of Portland cement concrete be less than 6 in. in thickness.

Equation (2) was derived from theoretical considerations as being an approximate formula assuming no bond between the existing and overlay pavements. Equation (1) is an empirical expression developed from the results of full scale traffic tests where bond breaking layers were not used.

Although the flexural strength of concrete of the overlay does not appear in these formulas it enters into the computations in the determination of "h," the thickness of the equivalent single slab. The flexural strength of the existing slab does not enter into the computations. However, it has been found that a substantial difference in flexural strength in the two pavements would result in a very small change in thickness.

For convenience in determining the required thickness of Portland cement concrete overlays on existing pavements consisting of Portland cement concrete in accordance with the above formulas, the curves on Fig. 4 have been prepared. The thickness of the equivalent single slab is usually determined by the use of the Westergaard analysis.

Civil Aeronautics Administration Method of Design

Overlays on Existing Flexible Pavements

Bituminous or Flexible Overlays

The required thickness of bituminous or flexible overlay is determined utilizing the CAA design procedure for determining the thickness of new pavements.[6,7] On the basis of soil tests, drainage and climate, the soil group and subgrade classification of the soil underlying the existing pavement is determined, as well as the actual thickness and composition of each layer of the existing pavement. From the basic design curves[6,7] of which Fig. 5 is an example, the thickness of flexible pavement required for the particular wheel loading under consideration, assuming it is to be placed directly on the subgrade, is determined. The thickness obtained from Fig. 5 are the result of experience with aircraft whose tire pressures range from 60 to 120 psi. Specific tire pressures do not appear as a variable in any of the CAA charts. The difference between the total thickness as determined from the design curves and the thickness of the existing pavement represents the required thickness of overlay pavement. Certain adjustments to this required thickness may be made, depending on the condition of the existing pavement and the character of the materials in the overlay pavement. It is considered that one inch of bituminous surfacing in good condition is equivalent to 1-1/2 in. of aggregate base course.

Whether the overlay is to be of the flexible type or bituminous type depends entirely on the economics involved in the particular project. For a flexible overlay it is recommended that the thickness of base course be not less than 4 in. Subbase materials are not recommended in flexible overlays.

The following problem illustrates the CAA procedure. An existing runway,

resting on an E-6 soil, consists of 2 in. of bituminous surfacing, 6 in. of crushed stone base and 4 in. of quarry run subbase. It is necessary to strengthen the pavement for a single wheel loading of 60,000 pounds. The frost action is severe and the drainage is poor. With an E-6 soil this corresponds to a subgrade class of F57. In accordance with Fig. 5 the required thickness of pavement is

Bituminous Surfacing	2 in.
Crushed Rock Base Course .	8 in.
Subbase	10 in.
Total	20 in.

Since the existing pavement has a total thickness of 12 in. it is necessary to add an overlay 8 in. thick of which the upper 2 in. will consist of a bituminous surfacing. The remainder of the deficiency in thickness can be supplied in one of the following ways, depending on the condition of the existing surfacing and the character of the overlay pavement.

Case 1 - Assume that the bituminous surfacing in the existing pavement is severely broken and a crushed stone base course is to be used in the overlay pavement.

The required overlay pavement will then consist of:

Bituminous surfacing (new)	2 in.
Crushed Stone Base Course (new)	6 in.
Bituminous Surfacing (existing)	2 in.
Crushed Stone Base Course (existing)	6 in.
Quarry-run subbase (existing)	4 in.
Total	20 in.

Case 2 - Same as Case 1 except that the bituminous surfacing in the existing pavement is assumed to be in good condition. The required overlay pavement will then consist of:

	Actual Thickness	Equivalent Thickness
Bituminous Surfacing (new)	2 in.	2 in.
Crushed Stone Base Course (new)	5 in.	5 in.
Bituminous Surfacing (existing) . . . . is equivalent to 3 in. of base course.	2 in.	3 in.
Crushed Stone Base Course (existing)	6 in.	6 in.
Quarry-run subbase (existing)	4 in.	4 in.
Total	19 in.	20 in.

Case 3 - Same as Case 2 except that the overlay is to consist entirely of a bituminous mixture. The required overlay pavement will then consist of:

	Actual Thickness	Equivalent Thickness
Bituminous Surfacing (new)	2 in.	2 in.
Bituminous Binder (Levelling) Course (new) is equivalent to 5 in. of untreated base course	3 in.	5 in.
Bituminous Surfacing (existing) is equivalent to 3 in. of base course	2 in.	3 in.
Crushed Stone Base Course (existing)	6 in.	6 in.
Quarry-run subbase (existing)	4 in.	4 in.
Total	17 in.	20 in.

Portland Cement Concrete Overlays

If the overlay pavement is to be of Portland cement concrete then the existing flexible pavement is considered as a subbase for the concrete slab. The procedure is about as follows: From the basic design curves,[7] of which Fig. 6 is an example, the thickness of Portland cement concrete and subbase required for a particular wheel loading under consideration, assuming it is to be placed directly on the subgrade, is determined. The overlay pavement will then consist of the required thickness of Portland cement slab plus any deficiency in subbase that may exist. If the thickness of the existing pavement is greater than the requirements for subbase thickness determined from Fig. 6, no adjustment in thickness of new Portland cement concrete slab is permitted.

The following example illustrates the procedure. Assume that the existing pavement and the subgrade on which it rests are the same as for the previous example. According to the CAA procedure[7] the subgrade classification for concrete pavement design, assuming poor drainage and severe frost, is R_c. For an R_c subgrade and a single wheel load of 60,000 lb. the required thickness of concrete is 9 in. and of the subbase 10 in. Since the existing pavement is 12 in. thick no additional subbase is required and the 9 in. of concrete can be placed directly on the existing pavement, due consideration being given to proper levelling.

Overlays on Existing Rigid Pavements

Flexible Overlay

For flexible overlays on rigid pavements, the CAA makes use of the same formula as the Corps of Engineers with minor variations to fit its nomenclature and subgrade soil classification. This formula is

$$t_f = 2.5\,(Fh - h_e)$$

where t_f = Required thickness of flexible overlay

h = Required thickness of equivalent single slab placed directly on subgrade or subbase

h_e = Thickness of existing slab

F = Factor which varies with the subgrade class

Values of "F" corresponding to the different subgrade classes are as follows:

Subgrade Class	"F"
Ra	0.80
Rb	0.90
Rc	0.94
Rd	0.98
Re	1.00

To illustrate the procedure, assume that existing runways and taxiways are constructed of concrete 6 in. thick and are placed directly on an E-7 subgrade soil; frost action is negligible, drainage is poor and the corresponding subgrade class is Rb; the pavement is to be strengthened to support a single wheel loading of 75,000 lb. For these conditions

h_e = 6 in.

h = 10 in. for runway (Fig. 6)

h = 13 in. for taxiway (Fig. 6)

F = 0.90

t_f = 2.5 (0.90 x 10 - 6) = 7.5 in. for runways

t_f = 2.5 (0.90 x 13 - 6) = 14.25 in. for taxiways

The CAA requires a minimum thickness of non-bituminous base course of 6 in. as well as 3 in. of bituminous surfacing when flexible overlays are constructed on rigid pavements.

If adequate subbase has been provided under the existing concrete pavement in accordance with the requirements in Fig. 6, the value of 0.80 for the factor "F" can be used in all cases. This condition would be equivalent to an Ra subgrade class. Since, in most cases, the subbases under the older pavements will not conform to these requirements, especially for the heavier loadings, the following table has been prepared to aid in selecting an appropriate value of "F."

Value of "F" when subbase under existing pavement conforms to requirements for subgrade class indicated below:

Subgrade Class	Ra*	Rb	Rc	Rd	Re
Ra	0.80	-	-	-	-
Rb	0.90	0.80	-	-	-
Rc	0.94	0.90	0.80	-	-
Rd	0.98	0.94	0.90	0.80	-
Re	1.00	0.98	0.94	0.90	0.80

* Figures in this column apply when no subbase has been provided:

As an explanation of the above if the design must be based on an Rd subgrade and the subbase thickness provided under the existing pavement conforms to the requirements, in accordance with Fig. 6, for an Rb or Rc subgrade, then the values of 0.94 and 0.90, respective, will be used for "F."

Bituminous Overlays

The required thickness of bituminous overlay is determined on the basis that one inch of bituminous surfacing is equal to supporting value to 1.5 in. of non-bituminous base. The thickness of bituminous overlay may be found by the formula

$$t_b = \frac{t_f}{1.5}$$

where t_b = Required thickness of bituminous overlay

t_f = Required thickness of flexible overlay

In the above example the equivalent thicknesses of bituminous overlays are found as follows:

$$t_b = \frac{7.5}{1.5} = 5 \text{ in. (Runways)}$$

$$t_b = \frac{14.25}{1.5} = 9.5 \text{ in. (Taxiways)}$$

Portland Cement Concrete Overlay

The required thickness of concrete overlays on rigid pavements are determined in the same manner as described in the Corps of Engineers procedures except that Fig. 6 is used as the basic design curves for determining the required thickness of rigid pavement placed directly on the subgrade or subbase. Also, in those cases where a subbase is necessary but has been omitted in the original construction, or is less than 6 in. in thickness, the thickness of concrete obtained from Fig. 6 is increased one inch for a single wheel loading of 15,000 pounds to two inches for a single wheel loading of 100,000 pounds, with proportionate increases within the range of wheel loadings. The reason for this is that the thickness of concrete provided in the design curve is based on the provision of a subbase varying in thickness with the character of the subgrade and the wheel loading. With no subbase, an increase in thickness of concrete is required. Of course, no correction is necessary if the subgrade corresponds to the Ra class.

To illustrate the procedure, assume that an existing runway of 6 in. of concrete rests on a 6-in. subbase. It is necessary to strengthen the pavement to support a single wheel loading of 75,000 pounds. The subgrade soil is E-7; frost action is negligible and drainage is poor. These conditions correspond to subgrade class Rb.

According to Fig. 6 the required thicknesses of Portland cement concrete slab and subbase are 10 in. and 8 in., respectively. Since 6 in. of subbase has been provided no adjustment need be made in the required single slab thickness.

Assuming that the existing pavement is in good condition and no levelling course is necessary between the existing and the new slabs, the required overlay thickness (h_c) is found from Fig. 4b as follows:

$C = 1$ $\quad h = 10$ in. $\quad h_e = 6$ in. $\quad h_c = 6$ in.

Overlays on Existing Flexible Pavements

The required thickness of bituminous or flexible overlay is determined by utilizing the design procedure developed by the Navy for new pavements.(2,9) This procedure requires the evaluation of the moduli of deformation of the subgrade E_2 and of the existing pavement E_1 by means of plate bearing tests. To simplify the procedure it is assumed that the modulus of deformation E_3 of the overlay is the same as the modulus of deformation E_1 of the existing pavement. It is stated that this assumption is on the conservative side, especially if the overlay consists of a bituminous mat, because the modulus of deformation of a bituminous overlay will most always exceed the modulus of an existing flexible pavement composed of a base course and a bituminous wearing course. In the Navy design, the Burmister equations(10) are regarded as sufficiently accurate for use in obtaining a first estimate or approximation to the required pavement overlay thickness. Final revisions of this first estimate are made after making plate loading tests.

To further simplify the problem it is assumed that the load distributing power of a bituminous surfacing is twice that of an equal thickness of base course. Thus 2 in. of a superior type of bituminous surfacing is equivalent to 4 in. of base course in load distributing power. It is stated that this is not an arbitrary assumption but is the result of actual observations. A flexible pavement consisting of 7 in. of base course and 3 in. of high quality bituminous surfacing would be considered in the computations as a base course, 13 in. in thickness. For a flexible overlay the Navy recommends that the thickness of base course if used be not less than 4 in.

By making these simplifying assumptions the overlay problem essentially resolves itself to the solution of a two layered system. On the other hand, overlays may be required on existing pavements which in addition to base courses have subbase courses. If the subbase course is a fairly low strength material (less than soaked CBR of 30) it may be neglected in the computations. However, if it is of appreciable strength (greater than CBR of 30) it must be taken into account in the analysis. The introduction of a subbase course results in a three layered system, the treatment of which is covered under Portland cement concrete overlays.

Bituminous or Flexible Overlays

The following example is taken from the Navy design manual(9) and illustrates the procedure for a two layered system. An existing runway pavement consists of 6 in. of base course and 2 in. of bituminous surfacing. It is required to know the thickness of a bituminous or flexible overlay for a 50,000-lb tire load at an inflation pressure of 150 psi (contact pressure assumed as 165 psi). From data obtained by loading on the subgrade with a 30-in. plate the unit load on the plate for a deflection of 0.2 in. is 25 psi. From data obtained by loading a 30-in. plate on top of the existing pavement a unit load of 58 psi caused a deflection of 0.2 in.

The first step is to find the modulus of deformation (E_2) of the subgrade.

$$E_2 = \frac{\pi(1-u^2)pa}{2S} = \frac{1.18\ pa}{S}\ \text{(when } u=0.5\text{)} \qquad (3)$$

where p = applied pressure on the subgrade in psi on the plate at a deflection of 0.2 in.

a = radius of the plate in inches.

S = deflection in inches. Limiting deflection is assumed to be 0.2 in. for bituminous pavements.

$$E_2 = \frac{(1.18)\ (25)\ (15)}{0.2} = 2210 \text{ psi}$$

The next step is to determine the settlement factor "F" of the pavement from the expression

$$F = \frac{E_2 S}{1.18\ pa} \qquad (4)$$

In this instance "p" is the unit load on the plate placed on the existing pavement. Thus

$$F = \frac{(2210)\ (0.2)}{(1.18)\ (58)\ (15)} = 0.43$$

The third step is to determine the modulus of deformation of the existing pavement (E_1). From the influence chart (Fig. 7) find the ratio E_2 tp E_1 corresponding to F = 0.43 and h/a = 10/15 = 0.67 or h = 0.67 a. Thus $E_2/E_1 = \frac{1}{50}$ and $E_1 = 50\ E_2 = (50)\ (2210) = 110{,}500$ psi. In the computation it was assumed that "h," the thickness on the existing pavement is 10 in. which takes into account the fact that 2 in. of bituminous surfacing is equal in load distributing power to 4 in. of base course.

Having determined the moduli of deformation E_1 and E_2, the final step is to compute the settlement factor "F" with the applied pressure of 50,000 lb wheel load (165 psi) and determine "h" the required over-all thickness of the pavement including the existing pavement. Then

$$F = \frac{E_2 S}{1.18\ pa}$$

$$= \frac{(2210)\ (0.2)}{(1.18)\ (165)\ (10)} = 0.18$$

In this instance "a" is the radius of an equivalent circular area corresponding to the circular area for the 50,000 - lb. load at 165 psi.

Entering Fig. 7 we find that for a F of 0.18 and $E_2/E_1 = \frac{1}{50}$, h/a = 1.7 or h = 1.7a = 1.7 x 10 = 17 in. The thickness of the overlay should then be 17-10 - 7 in. Note that the 10 in. is the equivalent thickness of the existing pavement and not the actual thickness. The overlay of 7 in. would probably be of the bituminous type since the minimum thickness of stabilized aggregate base course is limited to 6 in.

Portland Cement Concrete Overlays

The procedure for determining the thickness of Portland cement concrete overlays over existing flexible pavements is identical with the procedure used by the Corps of Engineers which has previously been described.

Overlays on Existing Rigid Pavements

The required thickness of Portland cement concrete overlay is determined in two ways. When the separation of levelling course between the two slabs exceeds 6 in. the thickness of the new slab is determined by loading with a

30-in. plate directly on a trial section, consisting of the levelling course compacted on the old concrete pavement. The modulus of subgrade reaction "k" is determined and used in the Westergaard analysis to compute the thickness of concrete overlay. The thickness of the overlay is never made less than 6 in. regardless of the computations.

When the separation course is 6 in. or less the following formulas are used to determine the thickness of the overlay

$$f_1 = f_o \frac{E_1 h_1^3}{E_1 h_1^3 + E_2 h_2^3} \quad \text{- - - (5)}$$

$$f_2 = f_3 \frac{E_2 h_2^3}{E_1 h_1^3 + E_2 h_2^3} \quad \text{- - - (6)}$$

Where f_1 = maximum tensile stress in the upper (new) slab when the old slab is under it.

f_o = maximum tensile stress in the upper (new) slab when the old slab does not exist and the new slab takes its place and rests directly on the ground.

f_2 = maximum tensile stress in the lower (old) slab when it lies under the new slab.

f_3 = maximum tensile stress in the lower (old) slab when the upper slab does not exist.

h_1 = thickness of overlay slab - in.

h_2 = thickness of existing slab - in.

E_1 E_2 = are the moduli of elasticity of upper and lower slabs, respectively.

The combination pavement is overloaded if either f_1 or f_2 is of such magnitude as to provide a low factor of safety when the modulus of rupture of the upper or lower slab is divided by its corresponding f_1 or f_2. A safety factor of at least 1.5 is recommended.

The formulas above were developed by Dr. Henri Marcus of the Bureau of Yards and Docks. It was assumed that the bending moments carried by the slabs were in proportion to their rigidities. As in all theoretical treatment, a number of assumptions had to be made in the development of the formulas. Some of these assumptions are that the materials are perfectly elastic; that no friction exists between the interfaces of the slabs; and that there is no elastic deformation due to shear. The formulas are intended to apply when one slab rests directly on the other, hence any separation course is in reality a third layer. However, if this layer is relatively thin, no serious error is introduced by discarding its presence. Neglecting friction in the interface between the two slabs produces an error on the conservative side.

The use of the formulas is illustrated by the following example taken from the Navy design manual.(9) The thickness of a new Portland cement concrete overlay on an old slab 6 in. thick is required for a single tire load of 50,000 lb. at 150 psi tire pressure. The measured subgrade modulus, k, is 200 lb./in.^{3} The measured modulus of rupture of the existing slab is 690 psi, and that of the concrete for the new slab is 635 psi. The moduli of elasticity E_1

and E_2 of both old and new slabs is taken as 4,000,000 psi. The thickness of the existing slab is 6 in. and it is cracked to a moderate extent.

As a trial, assume that the thickness of the Portland cement concrete overlay is 7 in. First find f_o and f_3. These values are determined by the use of the Westergaard theory. From Fig. 8 (which is derived from the liquid subgrade theory used by Westergaard) it is seen that f_o = 930 psi and f_3 = 1195 psi. Now by substitution of numerical values in the right hand members of equation (5), it is found that f_1 = 570 psi. Similarly, and from equation (6), f_2 = 461 psi.

The factors of safety corresponding to the two stresses, f_1 and f_2, are, respectively, 635/570 = 1.11 and 690/461 = 1.28. These factors of safety are too low. By repeating the computations it is found that a thickness of 9 in. for the upper slab is required for a reasonable factor of safety. The thickness derived from the formulas is based on the assumption that there are no cracks in the existing pavement. However, the assumed condition does not exist since there is a moderate extent of cracking in the existing slab. To compensate for this, the thickness is increased by 10 percent (to the nearest whole number). Thus the overlay thickness is increased from 7 to 8 in. because of cracking. If the cracking in the existing pavement is very extensive, the thickness is increased by 25 percent.

Flexible Overlay on Rigid Pavement

In designing a flexible or bituminous type of overlay on an existing Portland cement concrete slab the Burmister analysis is used.[10] In this case the material on which the concrete pavement rests, the concrete pavement, and the flexible or bituminous overlay constitute a three-layer system. For a three-layered system the Burmister analysis is approximate only. In this procedure E_3 denotes the material on which the concrete pavement rests, E_2 the modulus for the existing concrete pavement which is taken as 4,000,000 psi, and E_1 the modulus of the overlay. In addition to the settlement factor, F, used in the two-layered system, an additional multiplying coefficient, f, is introduced.

By loading through a rigid plate, placed on the surface of a three layered system, the settlement equation is

$$S = 1.18\ pa\ \frac{Ff}{E_3} \quad - - - - (7)$$

and by loading through a pneumatic tire, the settlement equation is

$$S = 1.5\ pa\ \frac{Ff}{E_3} \quad - - - - (8)$$

The factor of 1.5 = $2(1-\mu^2)$, and μ = 0.5. For the three-layered system f is defined by the expression

$$f = \frac{S}{1.18\ pa}\ \frac{E_3}{F} \quad - - (9)$$

If the modulus of subgrade reaction k has been found by loading through a 30-in. plate, E_3 may be computed from the expression

$$E_3 = 1.18\ a\ k \quad - - - - (10)$$

The following example illustrates the procedure. Compute the thickness of a flexible overlay on a 6-in. concrete pavement resting on a subbase having a measured k of 200. The overlay is to be designed for a single wheel load of 50,000 lb. at 150 psi tire pressure.

From equation (10) $E_3 = (1.18)(15)(200) = 3{,}540$ psi. The modulus of subgrade reaction k, was measured with a 30-in. diameter plate, hence a = 15 in. The two layer coefficient, F, is found as follows:

since $h/a = \frac{6}{15} = 0.400$ and

$\frac{E_3}{E_2} = \frac{3540}{4{,}000{,}000} = \frac{1}{1{,}130}$, from Fig. 7 by interpolation, F = 0.23. In this step, h = 6 in. is the thickness of the existing concrete pavement and the thickness of overlay is zero.

The next step is to compute f from equation (9). In this expression p = 165 psi (contact pressure assumed to be 1.1 inflation pressure), a is 10 in. (radius of equivalent circle whose area $= \frac{50{,}000}{165} = 303$ sq. in.) and S = .05 in. Then

$$f = \frac{(0.05)(3540)}{(1.5)(165)(10)(0.23)} = 0.31$$

Using Fig. 7 consider f as F (0.31) and use a value for E_1 obtained by loading a 30 in. plate on a known thickness of the overlay when it is placed directly on the subbase utilizing the two layered equation (4). Assume that this has been done and that $E_1 = 100{,}000$ psi. By using $E_1/E_2 = \frac{100{,}000}{4{,}000{,}000} = \frac{1}{40}$ and interpolating in Fig. 7 h/a = 1.0 or h/10 = 1 and h = 10 in., the required overlay thickness. Since 3 in. of bituminous surfacing is equivalent to 6 in. of base, an overlay of 7 in.; 4 in. base and 3 in. of bituminous surfacing would suffice.

The foregoing procedure, is at best approximate. The figure of 0.05 in. rather than 0.20 in. is used as the maximum permissible deflection for concrete for the reason that the limiting deflection of the concrete, without cracking, must be restricted to 0.05 in.

CONSTRUCTION PROCEDURES

The Construction Procedures summarized in the next few paragraphs are those generally followed by all three of the agencies mentioned in this report.

Preparation of Existing Surfaces

Flexible Pavements

Before proceeding with construction of the overlay, steps should be taken to correct all defective areas in the existing pavement, base, subbase and subgrade. Localized areas of broken pavement should be removed and replaced with new pavement. Pot-holes should be cleaned and filled with a suitable bituminous mixture. Surface irregularities and depressions such as shoving, rutting, and "bird baths" should be levelled up by rolling where practical and by filling with a bituminous mixture. If considerable unequal settlement exists, a levelling course of a bituminous mixture will be required as part of the overlay. Cracks, one-half inch or more in width, such as may be encountered at construction joints should be filled with a mixture of sand

and asphalt, tamped in place and any excess removed level with the pavement surface.

After all repairs have been completed and prior to the placing of the first course of a bituminous overlay, the existing pavement surface must be swept clean of all dust, dirt and foreign materials and followed immediately by an application of a bituminous tack coat at the rate of 0.05 to 0.10 gallons per square yard. In the case of a flexible overlay, the base course layer can be placed directly on the existing surface without a tack coat. If a Portland cement concrete slab is to be placed directly on a flexible pavement, then the existing repaired surface should be sprinkled with water just prior to placing of the concrete, but no tack coat is necessary.

Rigid Pavements

Ordinary transverse, longitudinal and corner cracks in rigid pavements will need no special attention unless there is an appreciable amount of displacement and faulting of the separate slabs. If the subgrade is stable and no pumping has occurred, the low areas can be taken care of as part of the overlay and no other corrective measures are needed. On the other hand, if there is pumping at the slab ends or the slabs are subject to rocking under the movement of aircraft, it is desirable to improve the subgrade support by pumping a slurry of soil-cement, bituminous material, etc., to fill the voids that have developed under the slab.

In the event the pavement slabs are badly broken and subject to rocking because of uneven bearing on the subgrade, the rocking slabs can be broken into smaller slabs to obtain a firmer seating on the subgrade. Badly broken slabs which do not rock will not require any extensive repairs, since the design criteria make adjustments for such a condition in the design of the pavement thickness when the overlay consists of Portland cement concrete. In some cases it may be found desirable to replace certain badly broken slabs with new slabs before starting construction of the overlay. This will have to be determined on the merits of the individual job.

When the existing rigid pavements are to be covered with a flexible or bituminous overlay the badly broken slabs may be replaced with a bituminous mixture equal in thickness to the thickness of the old concrete slab. If the subgrade soil under the slab has become unstable due to accumulations of moisture, it should be removed to the required depth as determined by a thorough investigation at the particular location, and replaced with a suitable granular subbase or base course material. If the existing pavement is rough due to slab distortion, faulting or settlement, a project for bituminous overlay should make provisions for a levelling course of bituminous mixture before the resurfacing is commenced. If the project calls for a concrete overlay, a separation course of granular material or of a bituminous mix should be considered.

Very often the cracks in the concrete pavement continue through the bituminous overlay, particularly if the overlay is thin. In order to minimize the formation of cracks in the overlay, small strips of expanded metal or welded wire fabric have been placed over the cracks prior to placing the bituminous overlay. If the slab is badly cracked, the entire surface is covered with the fabric. The results of the few experiments with the use of expanded metal are encouraging. It is important to keep the fabric as flat as possible since the wire possesses considerable springiness which can be injurious to a thin bituminous overlay. The Texas State Highway Department has reported very satisfactory results with welded wire fabric in conjunction with bituminous resurfacing of old Portland cement concrete pavements. The California

Division of Highways is currently conducting a series of experiments with expanded metal fabric in connection with a four-inch thick bituminous overlay on a highway constructed some time ago of Portland cement concrete. The results of these tests should be of value to engineers interested in overlays.

Separation Courses between Existing and Overlay Slabs of Portland Cement Concrete

A Portland cement concrete overlay may be placed directly on the existing concrete or it may be placed on a separation course placed between the two slabs. When a separation course is not required, the old surface should be dampened repeatedly just prior to depositing the fresh concrete.

In some cases the existing pavement requires levelling to restore it to smooth grade before an overlay of uniform thickness can be placed on it. Also a separation course may be required to improve drainage conditions and meet grade requirements. The separation course should consist of a bituminous mixture or dense graded mechanically stabilized base course aggregate. If only a part of the area to be overlaid requires a separation course to improve drainage or for some other means it is recommended that a separation course be placed over the entire area in order to prevent non-uniformity of support.

There appears to be some difference in opinion as to the effect of the separation course on the overlay slab. The Portland Cement Association(13) indicates that experience with both actual pavements and in several full scale test pavements has shown that the use of a separation course leads to greater deflections and more breaking in the overlay slab than where separating courses are not used. This tendency is recognized and to minimize it, separation courses should have the maximum possible density and resistance to deflection or compression under load.

Joints in Portland Cement Concrete Overlays

It is essential to have the joints of a Portland cement concrete overlay in alignment with joints of the old pavement (within 1 ft. if possible). If the jointing pattern in the old slab is disregarded in designing the joints in the overlay, especially if the new slab is laid directly on the old without a separating course, cracks may be expected to develop in the concrete that is above the old joints. With a separating course between old and new slabs this tendency to crack the new concrete over old joints is reduced. It is not necessary, however, to match identical types of joints. Thus a contraction joint in the overlay can be matched or aligned with a construction, expansion, or weakened plane joint of the existing slab. All steel (reinforcing, tie bars and dowels) used in concrete resurfacing can be designed in accordance with the procedures used for new pavement. When designing tie bars and distributed steel the pavement thickness used should be the total thickness of old plus new slab, unless the existing slab contains tie bars and reinforcing. In this case the overlay thickness alone can be used.

THEORETICAL ANALYSES OF PAVEMENTS

The purpose of this discussion is to review briefly the status of analyses of simple pavements, both rigid (concrete) and flexible (bituminous), and to make a few suggestions in regard to overlay pavements.

Rigid Pavements

Theoretical analyses of rigid type pavements have usually considered the pavement to be a thin plate and the subgrade to be either a dense liquid or an elastic solid. The liquid subgrade assumption (Westergaard analysis) leads to a simpler analysis, and most rigid pavement designs, based on theoretical analyses, have used this assumption. In using this assumption, attention is confined to stresses and deflections of the pavement. No information in regard to stresses in the subgrade can be obtained by this analysis. Analyses of rigid pavements which are based upon the assumption of an elastic solid subgrade are more recent. The assumption of an elastic solid subgrade is more realistic since the subgrade is in reality a solid rather than a liquid. Moreover, with this assumption it becomes possible to take subgrade stresses into account in design. To date the "elastic solid" theory has not been used for the design of pavements chiefly because of the difficulties of determining the modulus of elasticity of the soil which this theory requires. Theoretical performances of rigid pavements on both liquid and solid subgrades are treated in some detail in Bulletin 65 of the Engineering Experiment Station of Kansas State College.(11)

Burmister of Columbia University has made a still more realistic approach by considering both the pavement and subgrade as elastic layers.(10) To assume the pavement to be an elastic layer should result in better values for subgrade stresses. However, because of analytical difficulties, use of Burmister's approach has been confined largely to determining pavement deflections. A simplification of Burmister's approach and giving essentially the same values for subgrade stresses was presented at the 1954 annual Highway Research Board meeting by Pickett and Ai.(12)

It is well known that a rigid pavement may not make contact with the subgrade at all points and that the subgrade is not perfectly elastic. Moreover, both the rigid pavement and the subgrade deform with time due to moisture changes and creep. Very little progress has been made in taking these factors into account in theoretical analyses. Their effects are evidently recognized and reflected in design formulas. For example, when a rigid pavement is not supporting wheel loads, residual flexural stresses are present, being tensile in the top and compressive in the bottom portion. This is shown by a tendency to warp against gravitational restraint. These flexural stresses are the reverse of those caused by loads in the interior and subtract from them. The presence of these residual flexural stresses makes it possible to use higher load stresses in design than would otherwise be practical because the actual stresses are the load stresses minus the residual stresses.

Flexible Pavements

Two main approaches have been used in theoretical analyses of flexible pavements. In one approach the higher modulus of elasticity of the pavement compared to the subgrade is neglected. Stresses are computed using the Boussinesq formulas for loading of a semi-infinite homogeneous elastic solid. According to this view the pavement must be strong enough to withstand the stresses within it and thick enough so that the stresses reaching the subgrade will not exceed the strength of the subgrade. On a qualitative basis this approach has some merit, but if the pavement and subgrade differ appreciable in moduli of elasticity, the computed deviator stresses, for example, will be so far from correct that the method must be regarded as unreliable. The deficiencies of the method should be realized and the method discarded in favor of better methods wherever feasible.

The other approach is that of Burmister for layered systems.

Mathematically this is the same as Burmister's method for rigid pavements. The effect of the higher modulus of elasticity of the pavement in reducing deflections and in reducing stresses in the subgrade is taken into account. However, as stated previously, this method has been confined largely to determination of pavement deflections. A source of error in using the Burmister equations for deflections results from a popular misconception. This is that the elastic properties of the soil below a certain depth have only a negligible effect on the stresses and displacements in the pavement and subgrade. The error is small as regards stresses, but is not small in regard to displacements. For example, if it may be assumed that the load transmitted from the pavement to the subgrade is uniform over a circular area of radius "a" and that below a depth "t" no displacement occurs, then the maximum deflection of the upper surface of the subgrade becomes

$$w = \frac{2\,(1-\mu)\,pa}{E}\, f\left(\frac{t}{a}\right)$$

where: $$f\left(\frac{t}{a}\right) = \frac{J_1(\alpha a)\, d\alpha}{\dfrac{4(1-\mu^2) + (\alpha t)^2 + (3-4\mu)\sinh^2 \alpha t}{(3-4\mu)\cosh \alpha t \sinh \alpha t - \alpha t}}$$

where:

- w = deflection at the surface of a pavement
- a = radius of the loaded area
- p = pressure to the pavement applied at the surface
- t = thickness of soil layer of modulus E
- E = modulus of elasticity of soil
- μ = Poisson's ratio

Values of $f\left(\frac{t}{a}\right)$ for various values of t/a and for four different values of μ follow.

	$f\left(\frac{t}{a}\right)$			
t/a	$\mu = 0$	$\mu = .25$	$\mu = .40$	$\mu = .50$
1.0	.487963	.449948	.385059	.297863
1.25	.566154	.527758	.471245	.368027
1.6667	.659577	.627028	.580356	.493267
2.0	.711025	.683036	.642096	.570308
2.5	.765247	.742714	.708061	.655218
3.3333	.821439	.804446	.777112	.740766
5.0	.879823	.868217	.849608	.824875
10.0	.939564	.933675	.924252	.911730
	1.0	1.0	1.0	1.0

Those who neglect the effect of change in modulus with depth use $f\left(\frac{t}{a}\right) = 1.0$.

It is evident from the table that this may be in considerable error if t is not much greater than a.

Similar results are shown by Tables 3 and 4, page 68 of Kansas State College Bulletin 65, where results are given for pavement deflection caused by loads on the pavement.

Another common error in using the Burmister equations is to assume

Poisson's ratio to be 0.5 for all layers. The assumption in regard to Poisson's ratio is not important in the Boussinesq case, but it is of considerable importance for layered systems. Poisson's ratio is not 0.5 for any solid. It may be as much as 0.4 for clay and as small as 0.25 for sand or crushed rock.

Overlay Pavements

The theory of elasticity, though certainly deficient, has been very helpful in understanding the performance of simple pavements. It is reasonable to suppose that it will be helpful in understanding the performance of overlay pavements. However, before it is feasible to use the theory of elasticity for overlay pavements, a great body of results must be made available for layered systems. Partial results, say for only one Poisson's ratio, or an inadequate number of layers, may be misleading. Surely an overlay consisting of rigid pavement over flexible requires a different body of information from that required by flexible over rigid.

An overlay of concrete on concrete presents the problem of bond between the two. This is complicated by the tendency of the newer concrete to shrink with respect to the older concrete. An understanding of this performance also needs analytical treatment.

CURRENT INVESTIGATIONS RELATED TO OVERLAY PAVEMENTS

A number of investigations are currently being conducted in the United States by the Corps of Engineers and the Bureau of Yards and Docks, the results of which may be of interest to engineers concerned with the design of overlay pavements. The Corps of Engineers is currently conducting studies to establish the requirements and advantages of prestressed concrete pavements for airfields. These studies will include limited small scale laboratory studies, a review of prestressing methods, and current experience with the design, construction and use of prestressed concrete roads and airfield pavements. On the basis of these studies, a design for a prestressed airfield pavement will be prepared and economic comparisons made with conventional concrete pavements. If the results of these studies indicate a reasonably favorable comparison between conventional concrete pavements and prestressed pavement, from the standpoint of costs and utility, it is planned to construct and test a full scale prestressed concrete pavement under repetitive traffic loading.

The Bureau of Yards and Docks through a contract with the Frederic R. Harris Company has constructed a test strip of prestressed Portland cement concrete 500 ft. in length and 12 ft. in width. The pavement is 7 in. thick and is prestressed with 5/8 diam. wires in a longitudinal direction and also wires in a transverse direction at sites selected for plate loading tests; static loads varying from 50,000 to 100,000 lb. having been applied with steel plates 8 and 20 in. in diameter. The effect of heat on the pavement on prestressing is also included in the study. The deflections, strains and pressures of concrete on subgrade, the changes in length of the slab, the loss of post-tensioning due to friction between strands and concrete and friction of concrete on subbase are factors which are being investigated.

The California Division of Highways is currently investigating the use of expanded metal mesh and welded wire fabric as a means of minimizing cracks in a Portland cement concrete pavement from working up through a bituminous overlay. Various sizes and shapes of expanded metal are being used in the investigation. The results of this work along with other work done along

these same lines in other states should be of value to the designer of airfield overlay pavements.

CONCLUDING REMARKS

A review of the methods contained in this report indicates that they are primarily empirical, in the sense that when a formula is used the values assigned to the terms in the formulas are chosen so as to ensure that the answer shall conform with observations of pavements in service or in full scale test tracks. There is nothing wrong with this method of approach. In fact it is very doubtful that an ideal solution will ever be evolved for determining thickness of overlay pavements. However, the Committee feels that efforts toward the development of an adequate theory should be pursued with vigor, since theory will be helpful in better understanding the performance of overlay pavements.

When considering an overlay over an existing concrete slab, it was noted that the thickness of a bituminous overlay obtained from the charts is often less than a Portland cement concrete overlay. This is rather difficult to explain quantitatively. One reason is of course the fact that a Portland cement concrete pavement is never placed less than 6 in. thick under existing construction practices. Another possible reason concerns stresses. A concrete overlay is designed to avoid overstressing both old and new slabs whereas when a bituminous overlay is used a limited amount of cracking is permitted in the base slab. In this connection, the amount of deflection that a Portland cement concrete slab can stand without causing cracks is small compared to the deflection that can be withstood by the bituminous overlay. The important factor in bituminous overlays is the prevention of cracks in the underlying slab from coming through the overlay. This is the reason that a number of airport and highway agencies specify a minimum thickness of 4 in. for bituminous overlays.

Respectfully submitted,

Henry Aaron
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G. Pickett
R. Horonjeff (Chairman)

February, 1955

ACKNOWLEDGMENTS

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SELECTED BIBLIOGRAPHY

1. U. S. Dept. of the Army, Corps of Engineers, Airfield Pavement Design, Flexible Pavements, Engineering Manual for Military Construction, Part XII, Chapter 2, July 1951.

2. American Society of Civil Engineers, A Comparison of Design Methods for Airfield Pavements, Progress report of the Committee on Correlation of Runway Design Procedures of the Air Transport Division, Proceedings Separate No. 163 Vol. 78, December 1952.

3. U. S. Department of the Army, Corps of Engineers, Airfield Pavement Design, Rigid Pavements, Engineering Manual for Military Construction, Part XII, Chapter 3, March 1954.

4. American Society of Civil Engineers, New Formulas for Stresses in Concrete Pavements of Airfields, H. M. Westergaard, Proceedings, May 1947, Vol. 73.

5. Portland Cement Association, Design of Concrete Airport Pavement, Chicago, Illinois, 1950.

6. U. S. Dept. of Commerce, Civil Aeronautics Administration, Airport Paving, May 1948.

7. U. S. Dept. of Commerce, Civil Aeronautics Administration, Airport Engineering Bulletin No. 2, April 1952.

8. U. S. Dept. of Commerce, Civil Aeronautics Administration, Airport Paving-Overlays, Tentative Standards, Airport Engineering Bulletin No. 3, January 1953.

9. U. S. Dept. of the Navy, Bureau of Yards and Docks, Airfield Pavement, Technical Publication Navdocks TP-Pw-4, January 1, 1953.

10. Burmister, D. M. The Theory of Stresses and Displacements in Layered Systems and Applications to the Design of Airport Runways, Proceedings of the twenty-third Annual Meeting of the Highway Research Board, 1943 pp. 126-144.

11. Pickett, Gerald, Raville, Milton E., Janes, William C. and McCormick, Frank J. Deflections, Moments and Reactive Pressures for Concrete Pavements, Bulletin No. 65. Manhattan, Kansas: Kansas State College, Engineering Experiment Station, 1951. 73 pp.

12. Pickett, Gerald and Ai, Daniel K. Y. Stresses in the Subgrade Under a Pavement of Rigid Type. A paper prepared for presentation at the 33rd annual meeting of the Highway Research Board, Washington, D. C., January 1954. Madison, Wisconsin, University of Wisconsin, Department of Engineering, 1954. 22 pp.

13. Portland Cement Association, Airport Resurfacing Survey, Draft Copy.

14. Wire Reinforcement Institute Inc., Welded Wire Fabric Reinforcement for Asphalt Concrete Resurfacing over Concrete Pavement Slabs, April 1954.

15. Philippe, R. R., "Structural Behavior of Concrete Airfield Pavements— The Test Program," Vol. 24, 1944 Proceedings of The Highway Research Board.

16. Philippe, R. R. and Mellinger, F. M., "Structural Behavior of Heavy Duty Concrete Airfield Pavements," Vol. 31, 1952 Proceedings of The Highway Research Board.

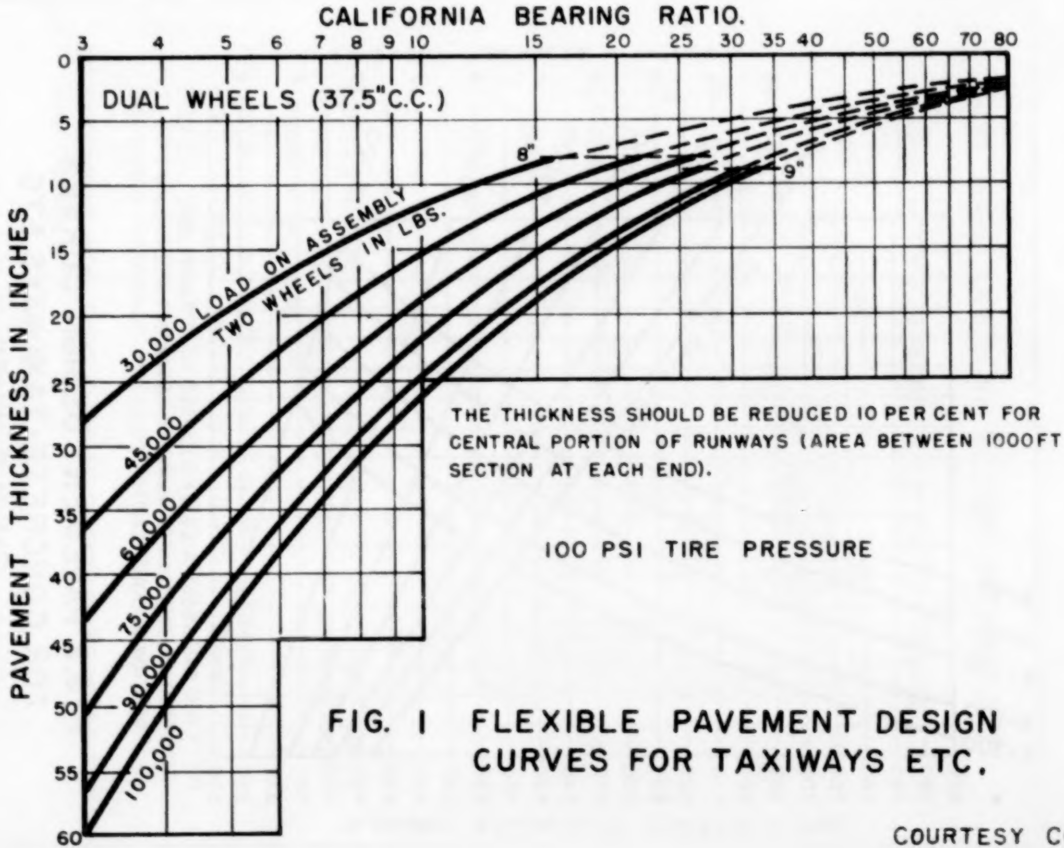
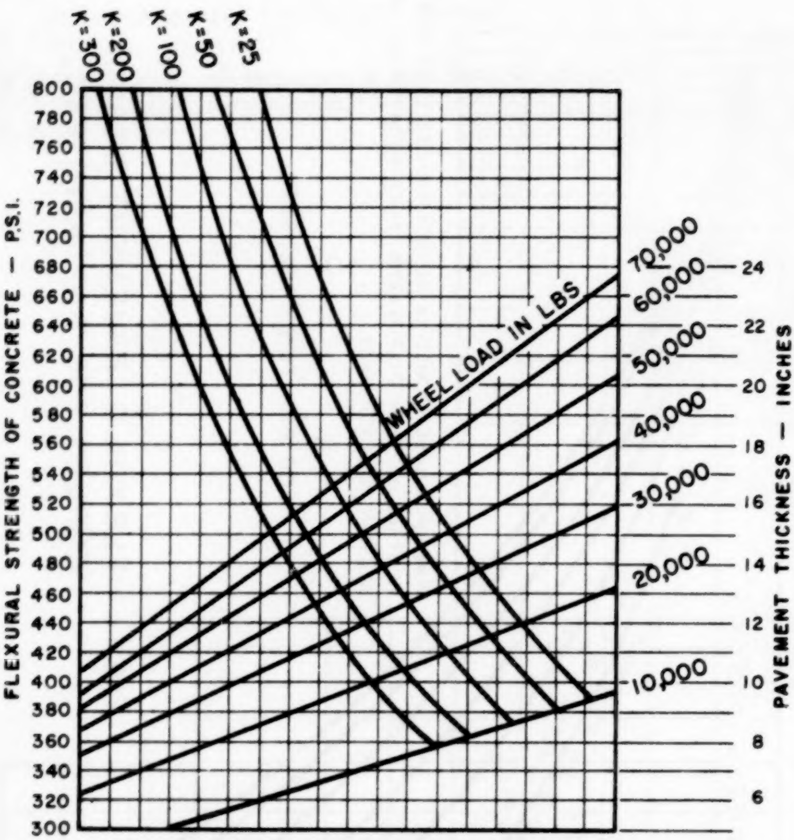


FIG. 1 FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.

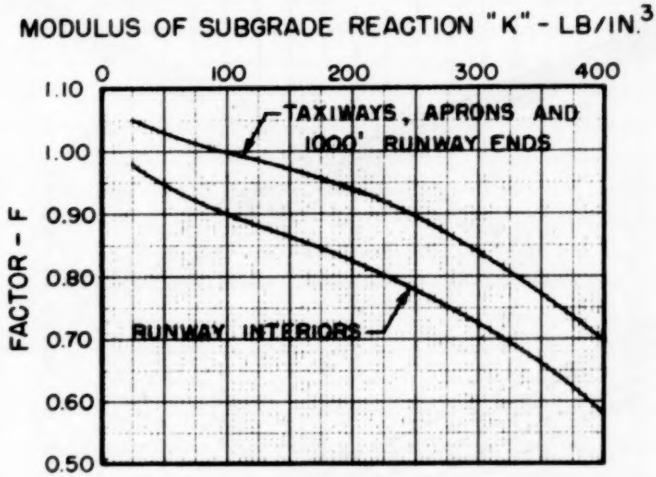
COURTESY CORPS OF ENGINEERS, U.S. ARMY.



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)

FIG.2 PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC.
SINGLE WHEEL
100 — PSI

NON-RIGID OVERLAY DESIGN PROCEDURE



(1) DETERMINE FACTOR, F, FROM ABOVE CURVES FOR FEATURE TO BE DESIGNED. ENTER CURVE FROM TOP WITH MEASURED SUBGRADE MODULUS "K".

(2) DETERMINE EQUIVALENT SINGLE SLAB THICKNESS, h_E, OF RIGID PAVEMENT TAXIWAY FROM CURVES IN <u>ENGINEERING MANUAL FOR MILITARY CONSTRUCTION</u>, PART XII, CHAPTER 3. THE FLEXURAL STRENGTH OF EXISTING PAVEMENT AND MEASURED SUBGRADE MODULUS "K" ARE USED.

(3) DETERMINE NON-RIGID OVERLAY THICKNESS REQUIRED FROM THE FORMULA

$$t = 2.5 \left[F h_E - h \right]$$

WHERE t = REQUIRED NON-RIGID OVERLAY THICKNESS
h = THICKNESS OF EXISTING RIGID PAVEMENT.

Fig. 3

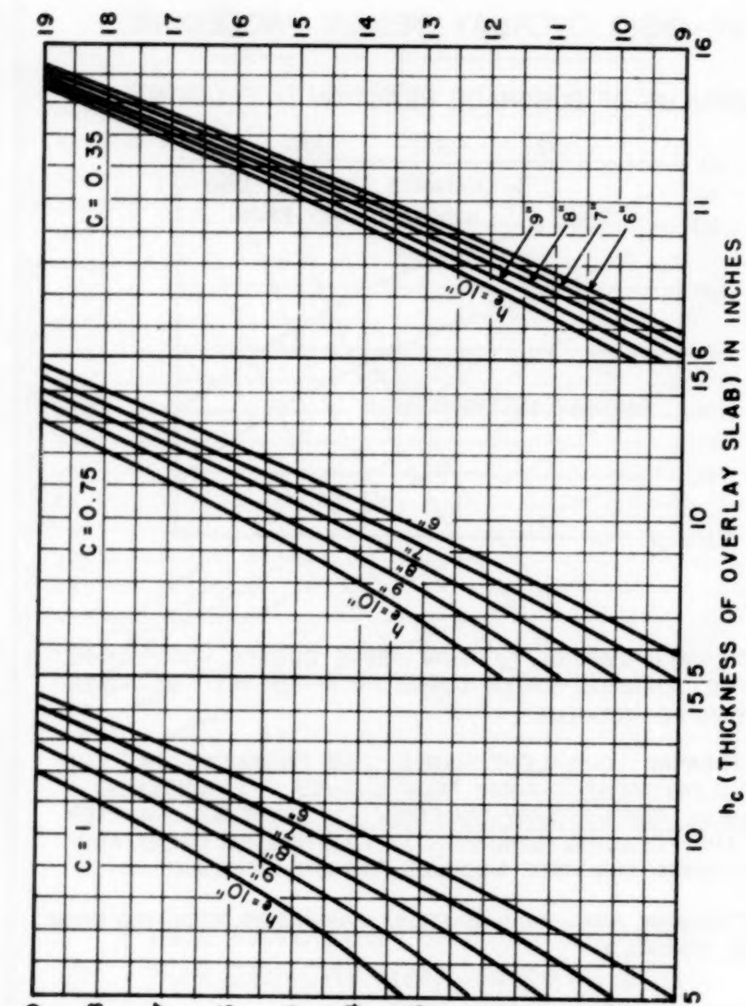


FIG.4A CONCRETE OVERLAY ON RIGID PAVEMENT

$$h_c = \sqrt{h^{1.87} - Ch_e^{2}}$$

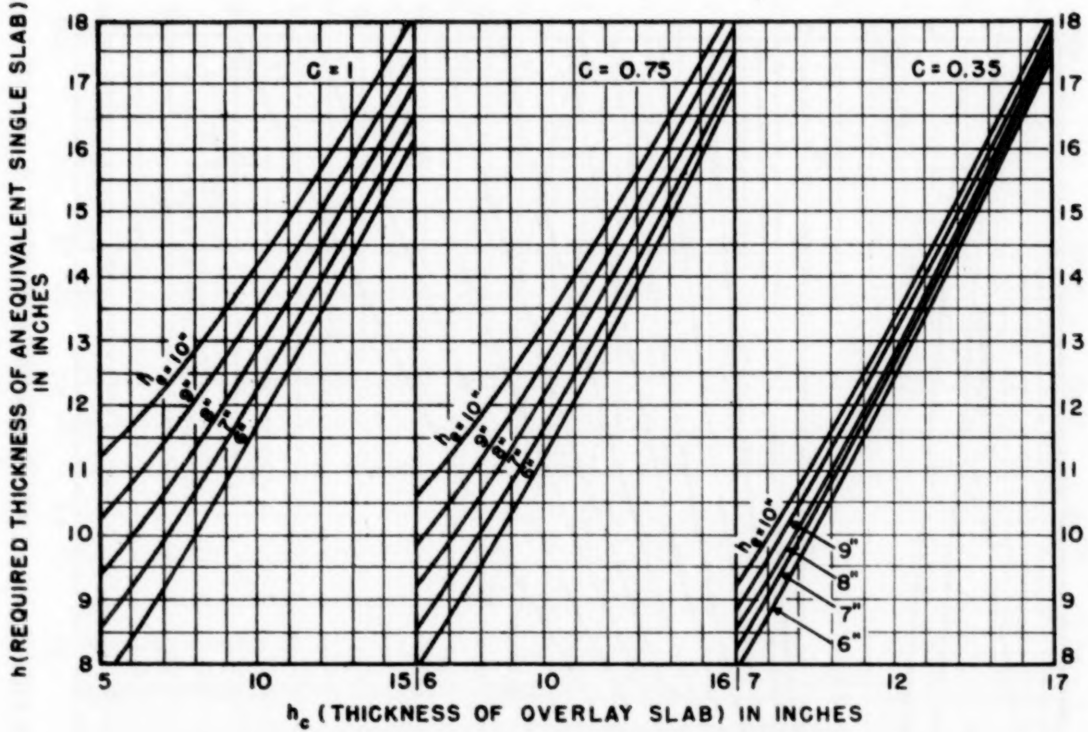


FIG. 4B CONCRETE OVERLAY ON RIGID PAVEMENT

$$h_c = \sqrt{h^2 - Ch_e^2}$$

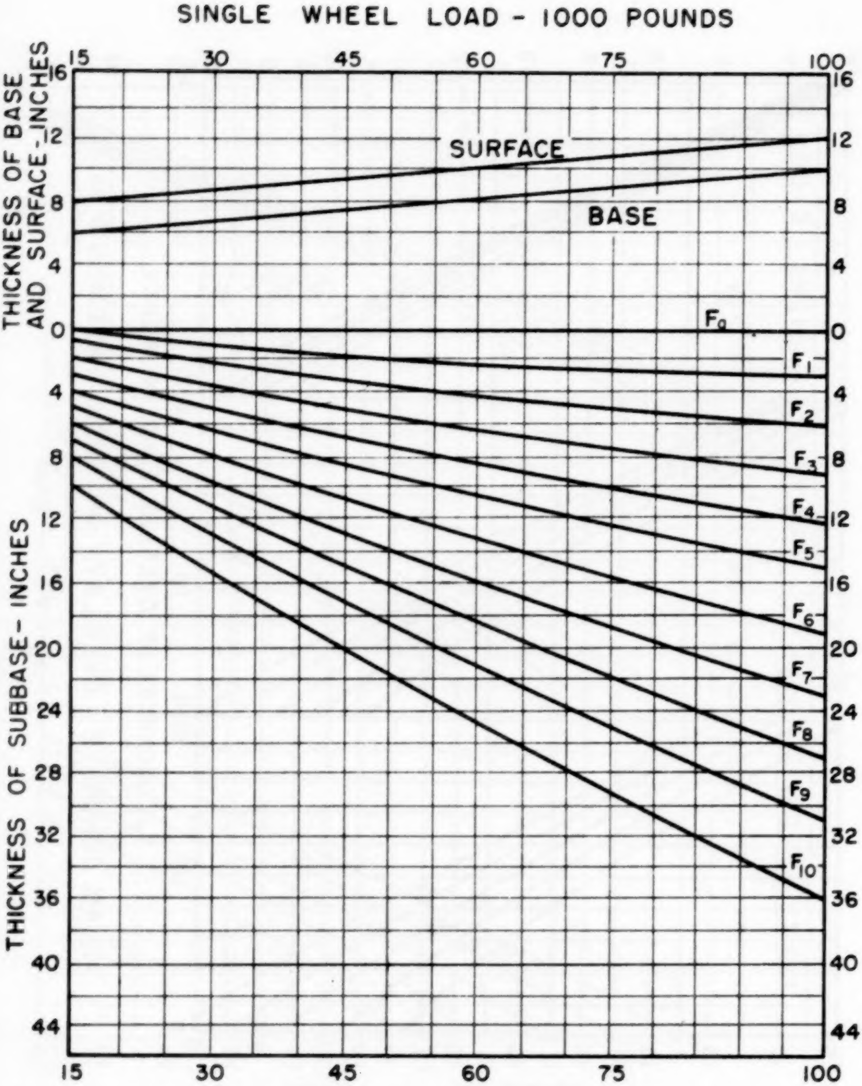


FIG. 5 FLEXIBLE PAVEMENT - NON BITUMINOUS BASE RUNWAYS

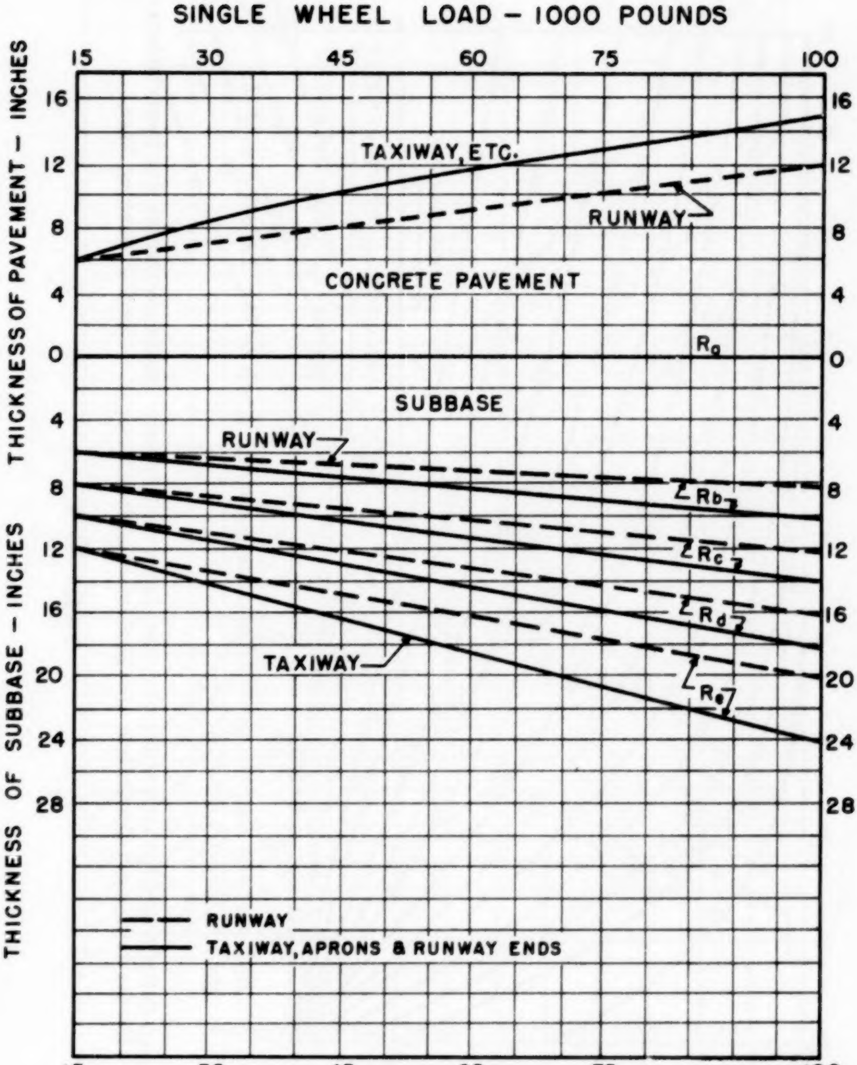


FIG. 6 RIGID PAVEMENT

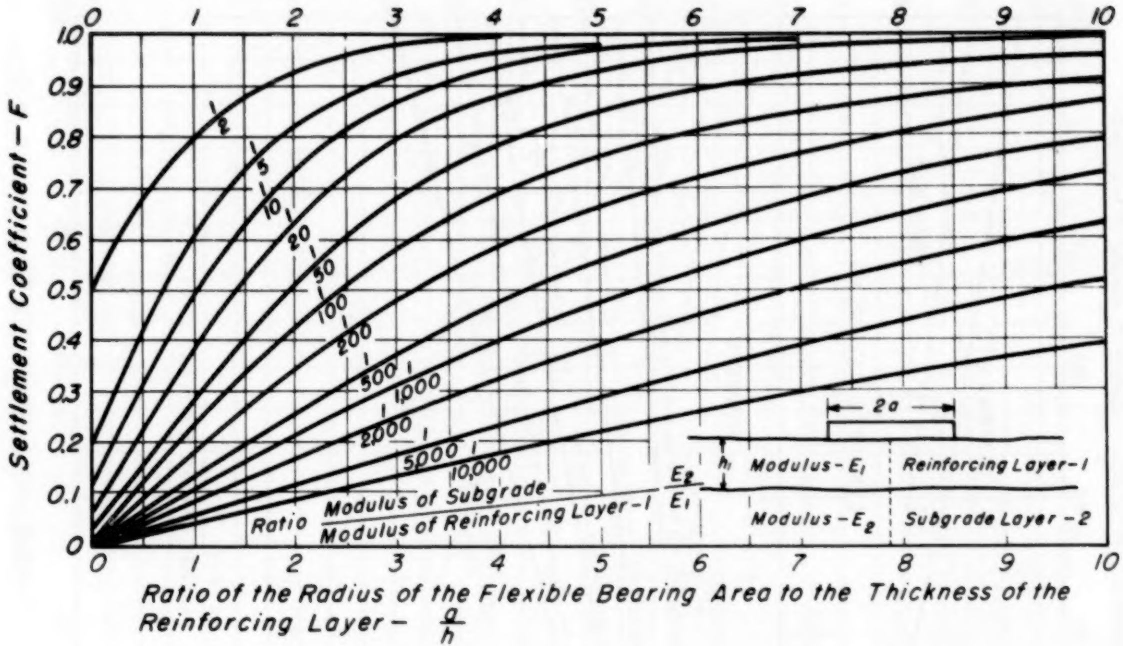


Fig. 7. Load-Settlement Characteristics of a Two-Layer Soil System. Influence Curves and Basic Relations for the Settlement Coefficient -F- Settlement at the Center of a Flexible Bearing Area.

$$S = 1.5 \frac{pa}{E_2} F$$

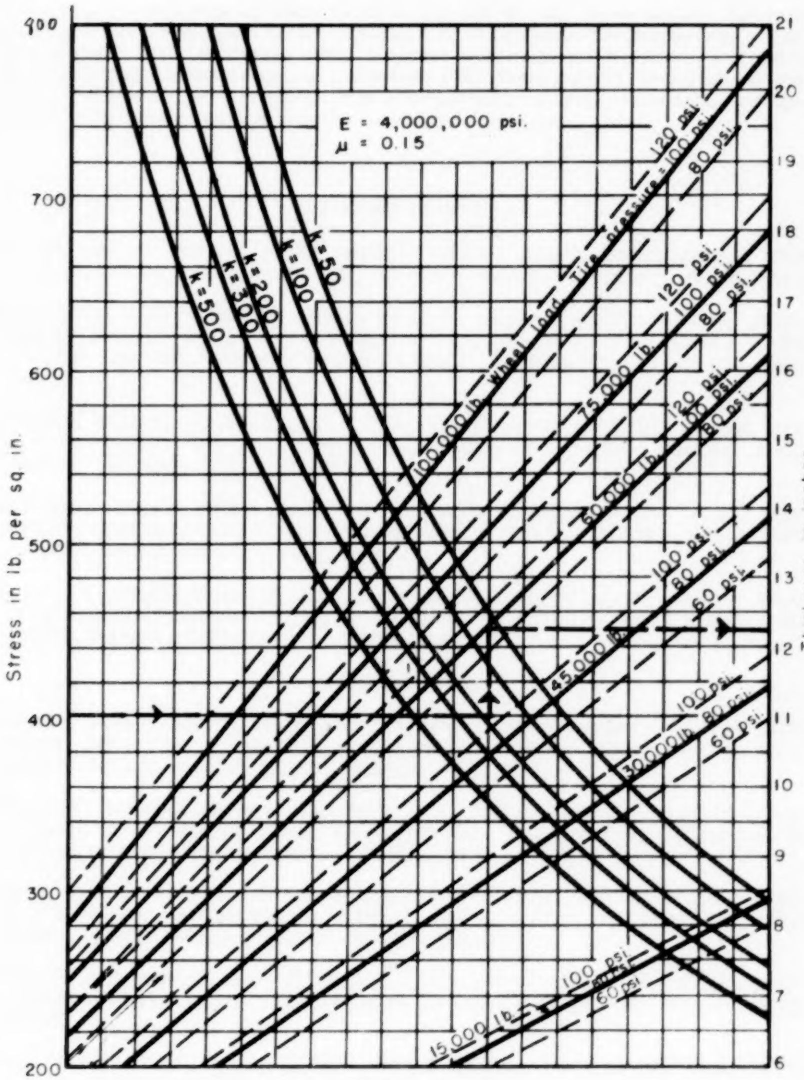


Fig. 8. Design Chart for Concrete Pavement Single Wheel

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AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)^c, 479(HY)^c, 480(ST)^c, 481(SA)^c, 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)^c, 488(ST)^c, 489(HY), 490(HY), 491(HY)^c, 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)^c, 502(WW), 503(WW), 504(WW)^c, 505(CO), 506(CO)^c, 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)^c, 519(IR), 520(IR), 521(IR), 522(IR)^c, 523(AT)^c, 524(SU), 525(SU)^c, 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)^c, 531(EM), 532(EM)^c, 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)^c, 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)^c, 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)^c, 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)^c, 569(SM), 570(SM), 571(SM), 572(SM)^c, 573(SM)^c, 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)^c, 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)^c, 596(HW), 597(HW), 598(HW)^c, 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)^c, 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)^c, 622(IR), 623(IR), 624(HY)^c, 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)^c, 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)^c, 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)^c, 655(SA), 656(SM)^c, 657(SM)^c, 658(SM)^c.

APRIL: 659(ST), 660(ST), 661(ST)^c, 662(ST), 663(ST), 664(ST)^c, 665(HY)^c, 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)^c, 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)^c, 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)^c, 700(PO), 701(ST)^c.

JUNE: 702(HW), 703(HW), 704(HW)^c, 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)^c, 710(CP), 711(CP), 712(CP), 713(CP)^c, 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)^c, 719(HY)^c, 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)^c, 727(WW), 728(IR), 729(IR), 730(SU)^c, 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)^c, 749(SA), 750(SA), 751(SA), 752(SA)^c, 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)^c, 759(SM)^c, 760(WW)^c.

AUGUST: 761(BD), 762(ST), 763(ST), 764(ST), 765(ST)^c, 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(EM), 773(SA), 774(EM), 775(EM), 776(EM)^c, 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)^c, 783(HW), 784(HW), 785(CP), 786(ST).

c. Discussion of several papers, grouped by Divisions.